Field Science—the Nature and Utility of Scientific Fields

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ABSTRACT **Fields are the fundamental sociological units of science. Despite their importance, relatively little has been written about their emergence, composition, structure, and function in the scientific enterprise. This essay considers the nature of fields and their important role in maintaining information and providing normative standards for scientific work. We suggest that fields arise naturally as a consequence of increasing information and scientific specialization. New fields tend to emerge as research communities grow, which may reflect biologically determined optima for the size of human groups. The benefits of fields include the organization of scientists with similar interests into communities that collectively define the next important problems to pursue. In the discipline of microbiology, fields are often organized on the basis of phylogenetic differences between microorganisms being studied. Although fields are essential to the proper functioning of science, their emergence can restrict access by outsiders and sustain dogmas that hinder progress. We suggest mechanisms to improve the functioning of scientific fields and to promote interdisciplinary interaction between fields.**

> The way in which our social world is constructed is part and parcel of our biological inheritance . . . There is a natural grouping of 150. That is the number of people you can have a relationship with involving trust and obligation—there's some personal history, not just names and faces.—Robin Dunbar (1)

Like other scientific disciplines, microbiology is subdivided into fields. For example, the American Society for Microbiology has 27 divisions, each representing a discrete field, such as clinical microbiology, microbial ecology, and medical mycology. Victor DiRita has recently written a thought-provoking essay that questions whether microbiological fields have become obsolete (2). DiRita suggests that consolidation into perhaps as few as four large interest groups might foster scientific integration and better serve the needs of society members. Here we explore the reasons that scientists self-organize into fields and how the shortcomings of fields might be ameliorated.

All of science is divided into areas that constitute fields. These areas range from the larger subdivisions, such as biology, physics, and astronomy, to smaller groups within those disciplines. For example, *Wikipedia* divides biology into dozens of subfields, including microbiology and physiology, with immunology considered a branch of physiology (3). Most scientists define themselves as belonging to a particular scientific field. As part of our continuing exploration of the state of current science, which includes prior essays on descriptive (4), mechanistic (5), important (6), specialized (7), diseased (8), competitive (9), and historical (9) science, we now examine how fields emerge and how their emergence influences the workings of science.

WHAT IS A FIELD?

Dictionaries define fields as "particular branches of study or spheres of activity or interest" (10). This definition certainly applies to scientific fields, but there are other definitions more narrowly crafted for science. Kuhn argued that a field of science should ideally have a paradigm: "Acquisition of a paradigm and of the more esoteric type of research it permits is a sign of maturity in the development of any given scientific field" (11). Darden had a more extensive list of requirements: "A central problem, a domain of items taken to be facts related to that problem, general explanatory factors and goals providing expectations as to how the problem is to be solved, techniques and methods, and concepts, laws and theories related to the problem which attempt to realize the explanatory goals" (12). A special vocabulary is often characteristic of a field (13). Although these definitions apply to some scientific fields, they do not work very well for microbiology. Perhaps the greatest limitation is that microbiological fields tend to be defined by common interests rather than by theoretical concepts. In microbiology, field definitions are often microbe-centric rather than focused on specific problems. For example, the authors of this essay are members of the *Cryptococcus* and *Salmonella* fields, respectively, which include individuals working on very different sorts of problems. These communities are centered around a microbe of choice. Membership in one of these fields requires contributing in some manner, but the contribution may range widely from structural biology to physiology to clinical medicine. Paradigmatic classification is perhaps more applicable to immunology, which contains some fields organized according to processes, e.g., antigen recognition, tolerance, autoimmunity, etc., but even there, one finds groupings that fail to conform to specific paradigms, such as the B cell, T cell, antibody, innate immunity, and mucosal immunity fields.

In considering the fields that are represented among the members of the American Society for Microbiology, we are struck by the many alternative ways in which scientists can be grouped. Apart from classification by phylogeny and process, fields may be defined by the meetings, journals, and organizations created to serve scientists with common interests. Determining field membership can sometimes be difficult. For instance, the authors of this essay are both in the field of microbiology, but one is in the

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field of mycology and the other in the field of bacteriology. Since both authors study how microbes cause disease, they also belong to the fields of infectious diseases and microbial pathogenesis. However, one predominantly studies problems in immunology while the other is focused on molecular biology, genetics, and biochemistry. To further complicate matters, both are interested in the workings of science, an interest that relates to the fields of philosophy, sociology, and even economics, as reflected in this essay.

The point of this exercise is to illustrate the difficulty of assigning individuals to particular fields with any degree of certitude, as individual scientists typically belong to multiple fields. In fact, field membership appears to be determined largely by self-definition by individuals according to their interests and is also dependent upon their acceptance by the other scientists working in a particular area. This implies a sociological dimension to field membership, which in turn suggests that field definition depends not only on scientific content but also on the other scientists with whom a scientist associates. From this vantage point, one can argue that associations and meetings define field membership. For example, those who attend the annual meetings of the American Society for Microbiology and the American Association of Immunology may be labeled "microbiologists" and "immunologists," respectively. Similarly, individuals may be classified by where they publish their scientific work, with those publishing in microbiology or immunology journals being assigned to those respective fields. Clearly, scientific field delineation, membership, and boundaries do not lend themselves to easy definition. Nevertheless, nearly everyone would agree that fields are important. We propose that a scientific field is a collection of individuals with a common interest in some aspect of science who interact on a regular basis. The interaction may be social, professional, and/or through the act of publication. This definition of a "field" differs from earlier ones by focusing on the human element as the key to field composition and yet incorporates interests, common goals, etc.

SCIENTIFIC FIELDS AS SOCIOLOGICAL UNITS OF SCIENCE

A scientific field viewed as a group of interacting individuals sharing a common interest is distinct from earlier definitions because it is based on human choices rather than on mere subject matter. The human interactions required by fields provide them with a social dimension, and fields may therefore be regarded as the sociological units of science. Fields emerge, grow, decline, or disappear depending on the interest level of individual scientists. For example, the field of phage biology did not exist prior to the discovery of phages, expanded markedly during the mid-20th century when it attracted many of the leading luminaries of molecular biology, and declined during the latter part of the 20th century as individuals became more interested in animal viruses, only to be reinvigorated in recent years by the genomics revolution, the realization that phages are critical mediators of gene transfer among bacteria and the transformative CRISPR/Cas9-based technology. The health of a field is generally proportional to the number of people interested in it, and fields can wither and die if abandoned by individuals who find other areas more worthy of study. Alternatively, the success of a field can also bring its own demise as a coherent subgroup in science. Consider, for example, the field of molecular biology, which emerged from the realization that proteins and DNA were molecules that could be studied, characterized, and manipulated. Progress in molecular biology spawned a wide variety of powerful techniques that went on to revolutionize other areas of biology. Whereas molecular biologists were once at the cutting edge of a revolution in biology, practically everyone in the biological sciences today can be considered to be a molecular biologist of one sort or another. Molecular biology has become so pervasive that the field of molecular biology has lost its once unique identity. Perhaps fields that are incorporated into multiple other fields have achieved the ultimate level of success. Scientific fields provide opportunities for professional friendships, collaborations, and interactions that promote science, but they are not immune to the problems found in society at large, such as gender and racial discrimination. Alice C. Evans, the first female president of the American Society for Microbiology, had to overcome gender discrimination when she proposed that brucellosis could be transmitted by unpasteurized milk. She persevered and was eventually vindicated despite fierce opposition from male contemporaries who "did not want any woman scientists" (14). Although women are now well represented in graduate training programs in the life sciences, the underrepresentation of women and minorities at senior academic levels remains an ongoing concern (15, 16).

THE NORMATIVE ROLE OF SCIENTIFIC FIELDS

A scientific field, once formed, plays an important role in achieving consensus on matters large and small, including the following. What are the next important questions to pursue? What are the appropriate methods to study a problem? What are the standards for data acquisition and analysis? In this manner, fields establish the rules by which science is done. However, the answers to these questions have a sociological dimension. The decision of what problems to pursue may be driven as much by the charisma and personalities of individuals in a field as by more objective factors. Fields may develop cultures based on accepted customs and ways of thinking. Some fields may encourage the open sharing of information and reagents, while others may foster secrecy and internecine competition. To understand the customs of a field, one must be in the field or have close contact with those who are. Fields are also the keepers of specialized knowledge, which is not always accessible to outsiders. For example, it may be common knowledge within a microbiological field that there are peculiarities associated with a particular microbial strain, but that information may be shared informally and may not be available to a scientist who relies on the published literature. In this regard, fields share some characteristics with guilds, which regulate competition by strictly controlling admission and the sharing of information. Those who seek to work in a particular field must obtain insider knowledge in order to publish and become accepted by a field. As repositories for specialized knowledge, fields carry the risk that the knowledge and beliefs within fields can develop into dogma, which becomes normative and can impede progress. The history of science is replete with examples in which prevailing dogma has impeded scientific progress. For example, Alphonse Laveran had to overcome the dogma that malaria was caused by noxious air to show that it was actually the result of a parasitic bloodstream infection (17). A nearly universally held belief in the tuberculosis field for the last half century was that antibody-mediated immunity had no role (despite many observations that suggested otherwise), which delayed appreciation of the importance of humoral immunity in tuberculosis (18, 19). More recently, the central dogma of molecular biology, in which information flows from DNA to RNA to proteins, has been challenged by the discoveries of reverse transcription and prions (20, 21). Although the central dogma remains essentially intact, scientists now appreciate that there are exceptions to the rule. The failure of reverse transcription and prions to conform to existing dogma initially delayed their acceptance (22, 23). It can be very difficult for a scientist to overcome established dogma, as publication and funding are controlled by established members of a field. Peer review can be seen as a two-edged sword that on the one hand helps to enforce rigorous standards of quality but on the other hand may stifle innovation and lead to stagnation. Fortunately, new information can lead to changes in paradigms. The infusion of new members can also invigorate a field, hence Planck's observation that "a new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die and a new generation grows up" (24).

FIELDS HAVE FUZZY EDGES

Determining the boundaries of a field can sometimes be difficult, for no two individuals in a field have identical interests, and many spheres of interest overlap. The interdisciplinary interests of scientists provide human links that interconnect fields. As Richard Feynman observed, "We make no apologies for . . . excursions into other fields, because the separation of fields, as we have emphasized, is merely a human convenience, and an unnatural thing. Nature is not interested in our separations, and many of the interesting phenomena bridge the gaps between fields" (25).

One need only attend the General Meeting of the American Society for Microbiology to see both the benefits and drawbacks of fields. Although the 27 divisions promote within-field interactions, they also contribute to the balkanization of science and create artificial barriers that can impede interdisciplinary interactions and transdisciplinary thinking.

FIELDS AS COMMUNITIES

Given the interdisciplinary nature of science, the dangers of dogmatism, and the fuzzy nature of fields, one might then ask, as DiRita has done (2), why have fields at all? One important reason is that fields provide a sense of community. Humans are social animals, and fields provide venues for socialization in professional areas. The anthropologist Robin Dunbar has observed that the size of social groups in primates is related to the size of the brain's neocortex ($r^2 = 0.61$) (26). He hypothesizes that this is the result of cognitive limits on the number of stable social relationships that can be maintained. A regression analysis of data obtained from various primate genera yields an estimated limit on human group size of 148 (95% confidence interval, 100 to 230) (27). Dunbar's number has been applied in settings as diverse as companies, government agencies, and social networks. Groups that exceed Dunbar's number may experience a loss of cohesion, which could be a factor in the emergence of new fields as old ones expand and diversify. The social organization of human enterprises that includes scientific fields may therefore be a direct reflection of the tendencies and limitations of the human brain. This suggests that the American Society for Microbiology's high-minded initiative to consolidate its 40,000 members into four large groups may ultimately fail to substitute for existing divisions because scientists, like all primates, crave intimacy and cohesive communities.

SUGGESTIONS TO IMPROVE FIELD PERFORMANCE

Given that fields are currently essential to the functioning of science, it may be preferable to identify ways to maximize their benefits while ameliorating their disadvantages. Here we provide some suggestions on how this could be accomplished.

I. **Give latitude to those who wander.** Fields can be hard on those who choose to relocate to other pastures. Such individuals may lose the benefits of field membership and may be perceived as not being seriously interested in the core subject matter of a field. However, allowing scientists to wander can benefit a field by sharing the specialized knowledge of the field with others (7) and fostering cross-fertilization. Being gentle on those who wander also increases the probability that those individuals will one day return with new knowledge and experiences gained from other fields, which in turn could enrich their original field.

II. **Promote interactions among fields.** Recognizing the importance of interdisciplinary, multidisciplinary, and transdisciplinary interactions, institutions, funding agencies, associations, journals, and meeting organizers should strive to create mechanisms to mingle and reassort individuals and concepts in ways that transcend conventional field boundaries and get scientists out of their comfort zones. This might involve research centers, conferences, sessions, or collaborative projects, just to name a few possibilities.

III. **Articulate dogmas.** A dogma is defined as "a principle or set of principles laid down by an authority as incontrovertibly true" (28). Certainly, there is no problem when a dogma is true, such the theory of heliocentrism. However, when dogmas are false or incomplete, they can impede scientific progress. As discussed earlier, all fields have dogmas, which influence the type of work that can be done and published through the mechanism of peer review. It is therefore useful for a field to articulate its existing dogmas. This exercise can prompt a healthy reevaluation of the evidence supporting current dogmas and focus work on outstanding questions in the field.

IV. **Define important problems.** In parallel, the most important unsolved problems in a field should be defined as the first step toward finding solutions. At the beginning of the 20th century, the German mathematician David Hilbert laid out 23 important problems, which helped to catalyze many novel solutions (29). This is relatively easy to do, as recently demonstrated by one of the authors of this essay at the conclusion of a meeting (30). The mere exercise of listing problems can lead to discussions that promote new scientific directions.

V. **Welcome outsiders.** Fields wish to grow and attract members but ironically put up many barriers that make it difficult for outsiders to join. Field membership includes publications and invitations to meetings, which in turn are determined by peer review. It behooves fields to be generous in welcoming outsiders by not creating undue obstacles for those wanting to enter a field. Growth is a sign of health, and all fields should strive to recruit new members. Established members can assist newcomers by educating them with regard to unstated dogmas, esoteric protocols, and the prevailing social dynamics of a field. Fields can promote diversity by being more inclusive of women, minorities, and young investigators when selecting speakers for meetings, recruiting journal editors, and electing society officers.

VI. **Avoid tribalism.** As fields have many similarities to tribes, it is unsurprising that fields can lead to tribalism. Tribalism is detrimental for science, for it encourages conformity and creates boundaries between groups. Resource scarcity may enhance tribalistic behavior that can interfere with the proper functioning of review groups, scientific organizations, meetings, etc. Tribalism can be avoided by focusing on what is good for science rather than what is good for a field and by promoting the fluid exchange of ideas and individuals between fields.

CONCLUSIONS

Scientific fields emerge when scientists with common interests self-organize into interactive units. The emergence of fields is an inevitable outcome, given the social nature of human beings and the necessity for specialization in the face of increasing knowledge. Fields make important contributions to the scientific enterprise, including the creation of cohesive communities, preservation of information, establishment of normative standards, and provision of mechanisms for peer review. However, fields can also lead to parochialism and dogmatism and may impede interactions between disciplines. Awareness of the potential liabilities of fields can help scientists to avoid these pitfalls.

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